



# Fiber Optic Components Qualification for Space Use at iXSpace : example of 980nm Pump Laser Diode

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# Outlines

- ▶ **Company Profile & Introduction to FOG Technology**
- ▶ **Qualification Strategy of the FOG Technology**  
*(included the Pump Laser Diode)*
  - Building the Qualification Test Plan
  - Procurement Scheme
  - Environmental Test Sequences
- ▶ **Results for the Pump Laser Diode**
- ▶ **Conclusion**
- ▶ **New project and prospects**

# Company Profile

## ▶ **iXSpace :**

- **100% Subsidiary of iXSea, Founded in Feb 2004**
- **Benefits from iXSea leadership on FOG technology**
- **Benefits from iXSea 25 years expertise on Fiber Optic Component**

## ▶ **iXSea ([www.ixsea.com](http://www.ixsea.com)) :**

- **World leader in**
  - navigation and positioning
  - Imagery and survey systems
  - Moorings and construction equipment
- **~180 employees**



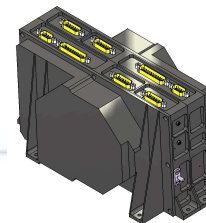
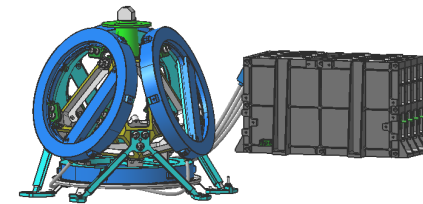
# Company Profile

## ► iXSpace develop with EADS Astrium a family of ITAR free Inertial Measurement Units (ASTRIX):

- **Fiber Optic Gyro (FOG) technology of iXSea** (*more than 2000 building axis*)
- **EADS Astrium expertise in the space activities**
- **Under CNES and ESA support / funding budget**
- **Covering a large range of space applications from LEO scientific missions to Telecom missions.**

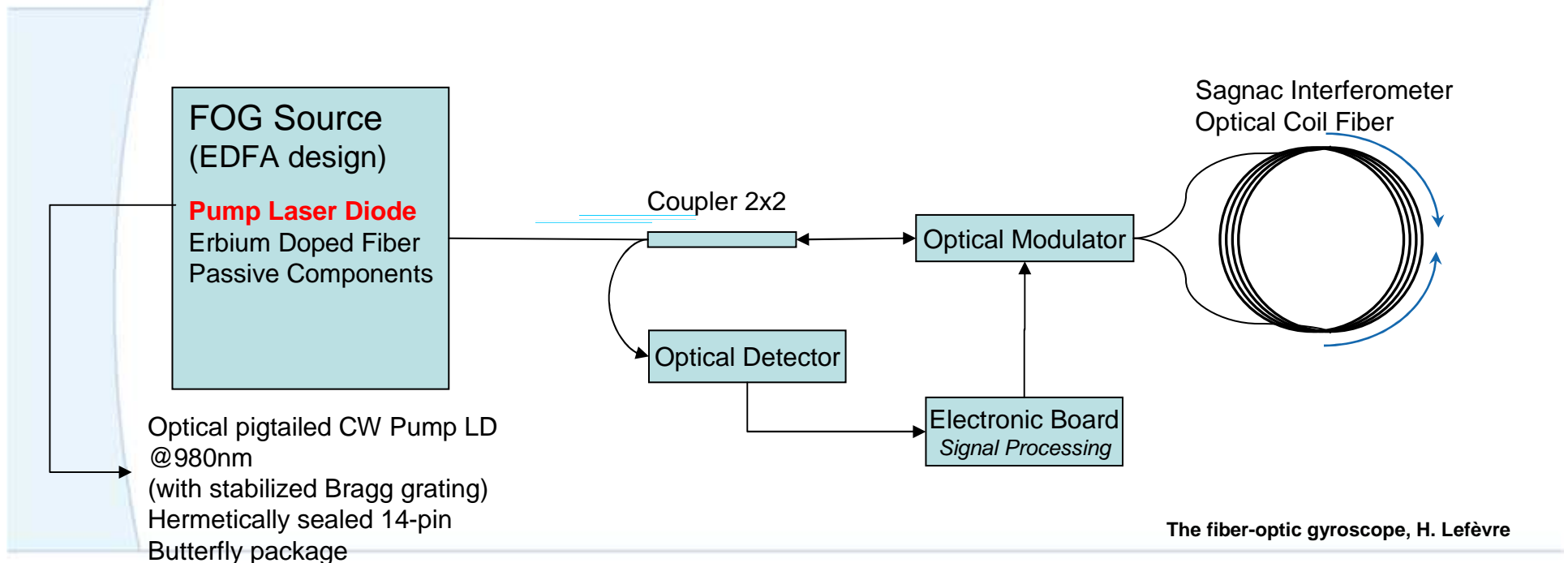
## ► Mission

- **Astrix 200 (0,001°/h) :**
  - Pleiades : Earth Observation
  - Aeolus : Atmospheric Wind Profile
- **Astrix 120 (0,01°/h) :**
  - Planck : Cosmic Background radiation
- **Astrix 120 HR (0,1°/h) :**
  - Galileo (*the first four satellites*)
  - COMS : Korean Satellite



# Introduction to FOG Technology

- ▶ a **Fiber Optical Gyroscope** is a rotation rate sensors, based on the **Sagnac Effect** which produces, in a ring interferometer, a phase difference between two counter propagative waves.



# Qualification of the FOG Technology

## ▶ Optical Parts Qualification :

- **Variety of optical device**
  - Opto-Electronics Parts:  
Pump laser diode; Optical detector PINFET; IOC (Integrated Optical Component)
  - Passive Optical Components:  
Optical isolator; Optical coupler; Bragg grating
  - Fiber Optic:  
Erbium doped fiber (for FOG Source); Fiber Coil (for Sagnac Interferometer)
- **No space qualified alternative : COTS qualification**
- **Batch procurement and qualification**

## ▶ Process / Material Qualification :

- **Bonding, fiber splicing, opto-electronics parts report ...**  
*Qualification for the Butterfly 14-pin package report*

# Building the Qualification Plan

## *A teamwork for the best compromise !*

### Project manager

*Cost & Planning*

### Component Engineer

*Opto-electronics Part Expertise  
Components Risks management Matrix*

### “PMP(#) Activity Plan”

- **Procurement scheme**
- **Elements to be tested (components, sub assembly, system)**
- **Environmental test sequence (Ageing, mechanical & radiations)**
- **Parameter to monitor and criteria**

### System Engineer

*Defines which parameter to monitor to assure that the equipment will function properly!  
(Wavelength stability, Optical power...)*

### Process & Material Engineer

*Process Risk management Matrix  
(operator dependant, repeatability..)*

### Space Environment Engineer

*Environmental constraint*

- *Radiative environment (cumulated dose, dose rate)*
- *Mechanical environment*
- *Thermal Environment*
- *Ageing : Storage + Mission life time (5 up to 15 years)*

(#) PMP : Parts Material & Process



# Qualification Strategy

- **Significant number of components**

*Strategic procurement of 130 Pump Laser Diodes*

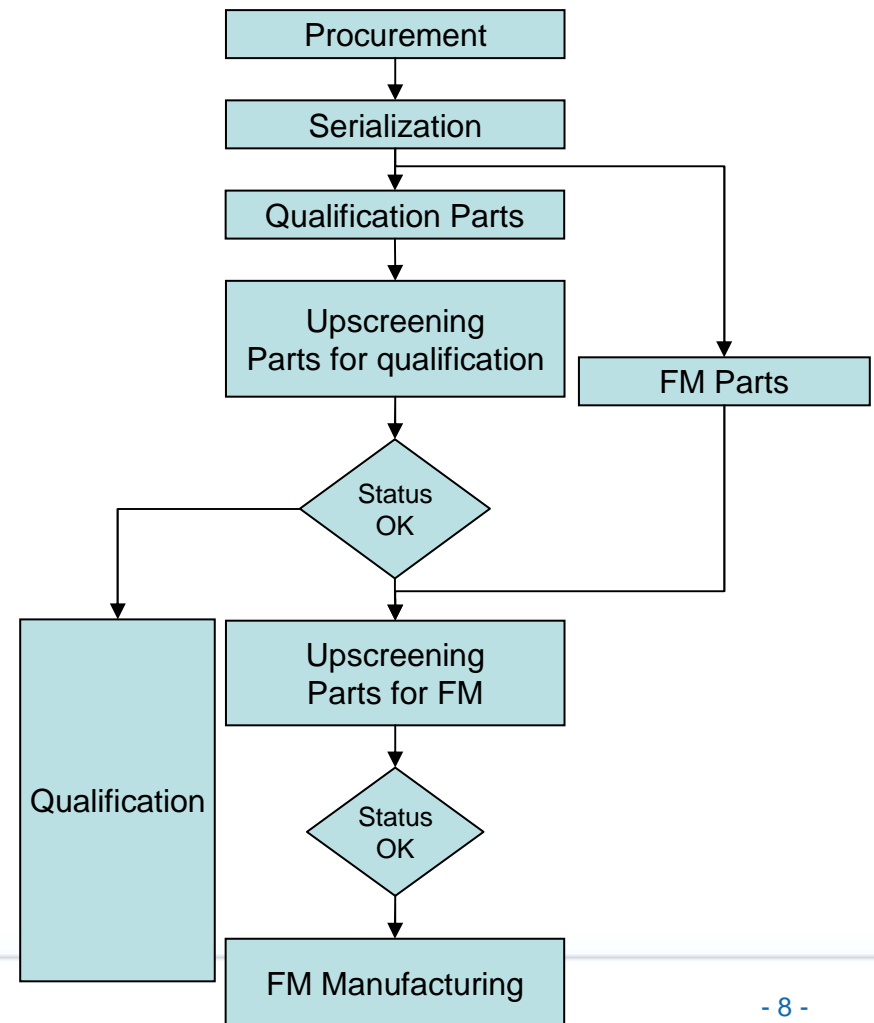
*Qualification of 3 batches of chip (3 wafers)*

- **Capacities of tests « limited »**

*Capacity of ovens, batches of 16 or 32 Diodes*

- **Programmatic issues**

*Qualification & Manufacturing « in the same time »*





# Procurement Scheme

- ▶ **Procurement set up**
  - **Selection of component (evaluation phase)**
    - Telcordia ?, preliminary testing, construction analysis...
  - **Definition of lot for each part**
    - batch of fiber, wafer for active parts...
  - **Procurement Specification**  
*(technical data from COTS datasheet, PFC reference...)*

# Procurement Scheme Construction Analysis

- ▶ **External Visual Inspection & X-Rays**  
*Identify packaging issues*  
*Ex : Pump Laser Diodes (butterfly)*
- ▶ **Seal test (gross and fine leak)**
- ▶ **PIND Test**
- ▶ **Internal Visual Inspection (Optical, MEB)**

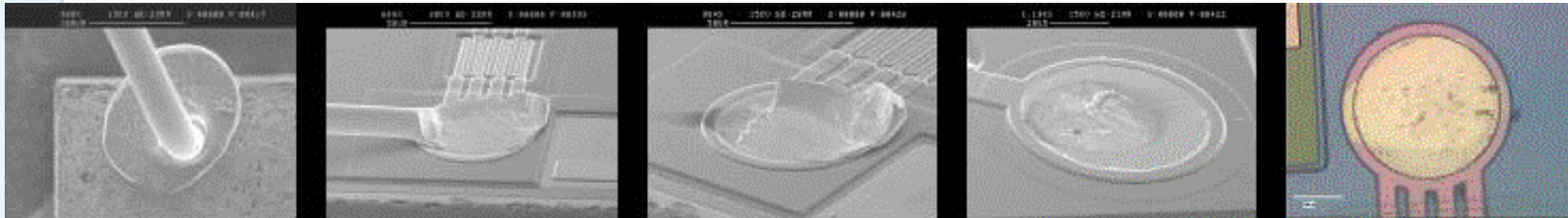


Solder joints for the output optical pigtail



Output optical pigtail

*Wirebonds issues, bond pull analysis...*



Ball bonding not centered, residual stick after bond pull test...

- ▶ **Micro-section & Material Identification**

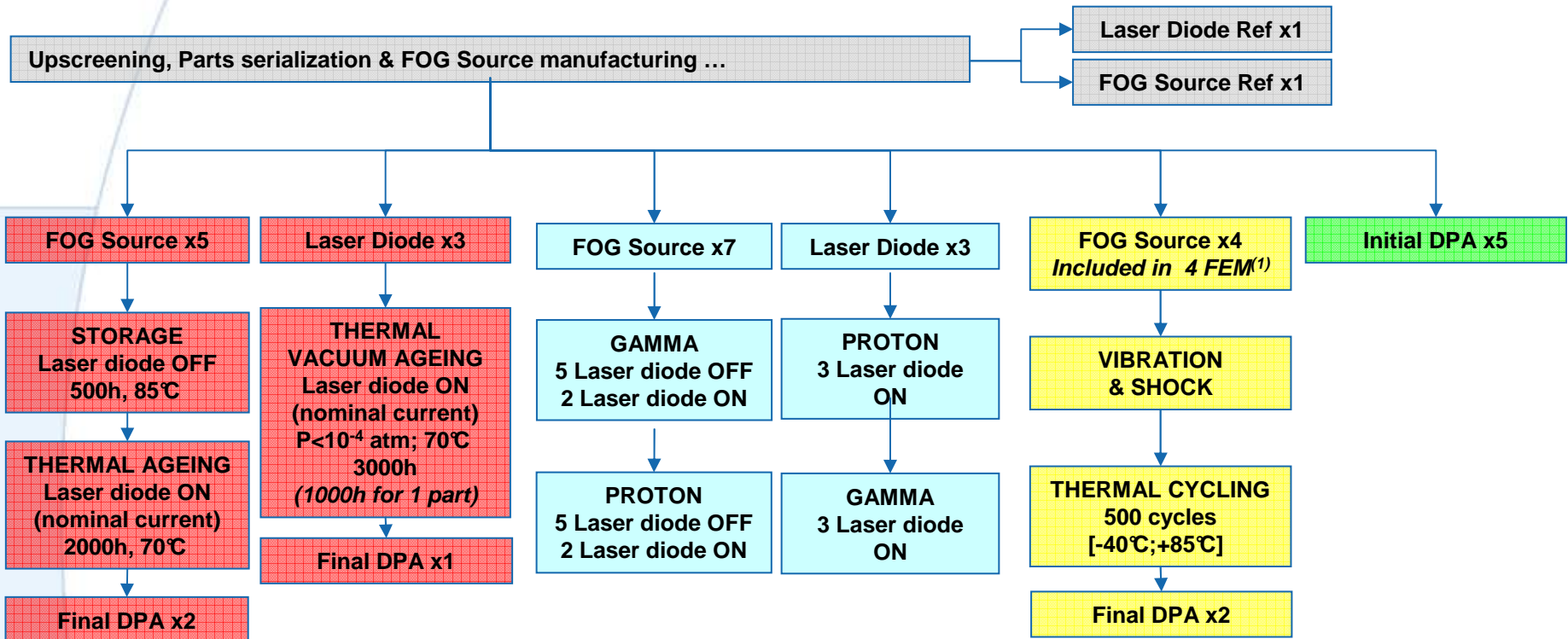


Output optical pigtail : transmission axis cut

# Procurement Scheme Up\_Screening

- **Based on :**
  - **Our knowledge about parts and manufacturer's process**
    - Screening of the chip & the module
  - **Astrium experts inputs**
  
- **IVE & X-Ray**
- **Up\_screening applied to the Pump Laser Diode**
  - **Thermal cycling (10 cycles, [-40°C;+85°C], 10°C/min )**
  - **Burn In (70°C during 240h)**

# Environmental Test Sequence



Initial & final measurements @T°C [-40°C, 25°C & 70 °C]

<sup>(1)</sup>FEM : Flight Electronics Module (Electronics Board + FOG Source = Flight Model)



# Parameter tested and criterion

## ● **FOG Source**

### ■ Measured parameters

Optical Power vs Pump Current *Function of Pump Laser Current :  $I_{mA}$  variable, [below the threshold current  $I_{th}$  up to  $I_{nominal}$ ],  $T_{ambient}$*

Fog Source Spectrum @  $I_{mA}$  constant ( $I_{OP}$ ),  $T_{ambient}$

### ■ Criterion

Fog Source Spectrum : Drift of the mean wavelength

Drift of the Optical Power (dB/krad)

Pump Laser Diode Current  $I_{nom}$  @  $P_{nom}$   $T_{ambient}$

## ● **Pump Laser Diode**

### ■ Measured parameters

Optical Power vs Pump Current *Function of Pump Laser Current :  $I_{mA}$  variable, [below the threshold current  $I_{th}$  up to  $I_{nominal}$ ],  $T_{ambient}$*

### ■ Criterion

Threshold Current  $I_{th}$  (Max value and drift <+/-15%)

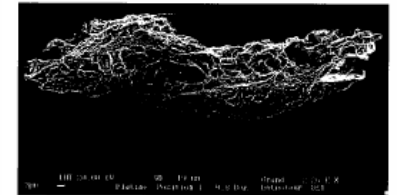
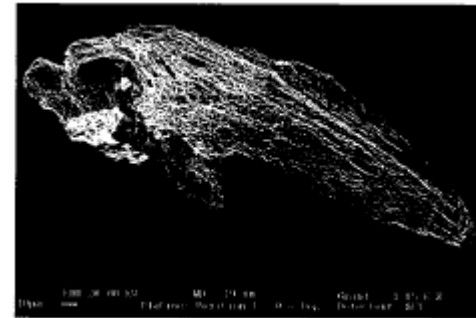
Nominal Laser Current  $I_{nom}$  @  $P_{nom}$   $T_{ambient}$

## Qualification Results Initial DPA

<b>Serialization x5 1459-DP2</b>	<b>5</b>
<b>External Visual Inspection</b> <i>MIL-STD-883E, Method 2009</i>	<b>5</b>
<b>PIND Test</b> <i>MIL-STD-883E, Method 2020</i>	<b>5</b>
<b>Seal Test</b> <i>Fine leak: MIL-STD-883E, Method 1014, Gross leak: MIL-STD-883E, Method 1014</i>	<b>3</b>
<b>Internal Visual Inspection</b> <i>MIL-STD-883E, Method 2017</i>	<b>3</b>
<b>Bond Pull Test</b> <i>MIL-STD-883E, Method 2011</i>	<b>3</b>
<b>Die Shear Strength Test</b> <i>MIL-STD-883E, Method 2019.5</i>	<b>3</b>
<b>Fiber Pull</b> <i>Telcordia method</i>	<b>2</b>
<b>Residual Gas Analysis</b> <i>MIL-STD-883E, Method 1018</i>	<b>2</b>

### ► Results :

- **One part was detected noisy during PIND Test**
- **Five particles were trapped (*SnPbAg solder particles*)**



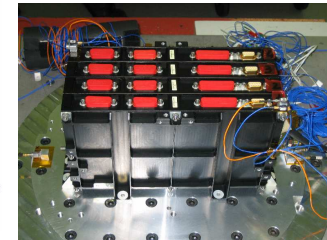
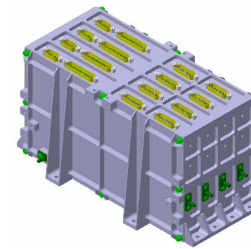
- **All strategic stock was PIND tested**
- **100 parts tested → 31 parts rejected**

# Qualification Results

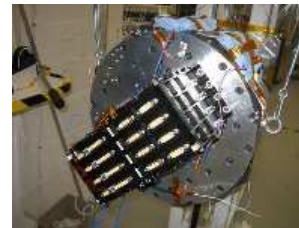
## FEM : Mechanical & Thermal Cycling Qualification

### ► Vibration (Sine & Random) + Shocks

Axis	Frequency (Hz)	Qualification level
Perpendicular to the mounting plane (Z axis) <b>29.95 gRMS</b>	20-90	+ 3dB/ oct
	90-350	1.0 g <sup>2</sup> / Hz
	350-560	-8dB/oct
	560- 2000	- 3 dB/oct



Axis	Frequency (Hz)	Acceleration (g)
Perpendicular to the mounting plane (Z axis)	100	40
	1200	1200
	1200	1200



■ Qualification successful

FOG Source (included Pump Laser Diode) : nominal working

## Qualification Results

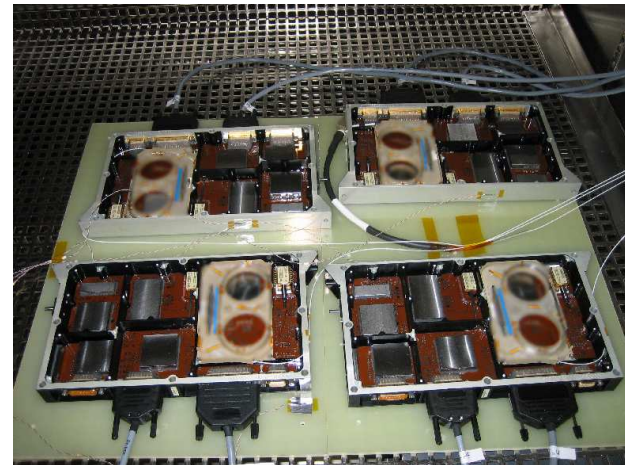
### FEM\* : Mechanical & Thermal Cycling Qualification

#### ▶ Thermal Cycling

- 500 cycles : [-40°C;+85°C], 10°C/min

*With measurements at 20, 100, 200, 300, 400 & 500 cycles*

- 20 cycles = Parts Qualification Level
- 200 cycles = Bonding Process Qualif Level
- 500 cycles = Parts Report Qualif Level



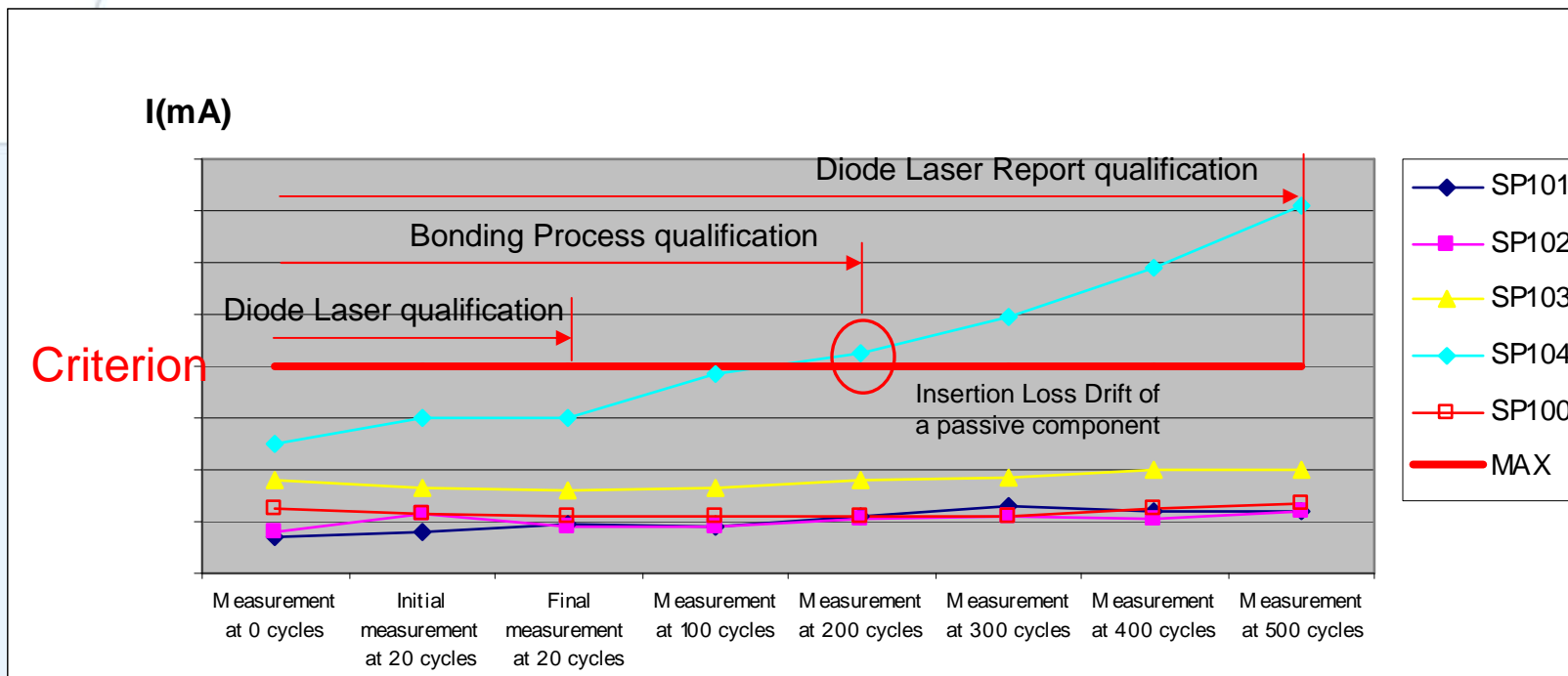
\*FEM : Flight Electronic Model (FOG Source including Pump Laser Diode)



# Qualification Results

## FEM\* : Mechanical & Thermal Cycling Qualification

### ► Thermal Cycling RESULTS



\*FEM : Flight Electronic Model (FOG Source including Pump Laser Diode)



## Qualification Results

# Pump Laser Diode : Proton & Gamma irradiation

## ► Proton Dose Qualification

- **3 Pump Laser Diodes**

- **Qualification level**

- Parts "ON", 60MeV, Steps :  $4.3e^{10}$  ,  $1.1e^{11}$  &  $1.8e^{11}p/cm^2$*

- **Qualification results**

- $I_{th}$   $I_{nom}$  : nominal value, No drift*

- **7 FOG Sources**

- ( ~7 Pump Laser Diodes)*

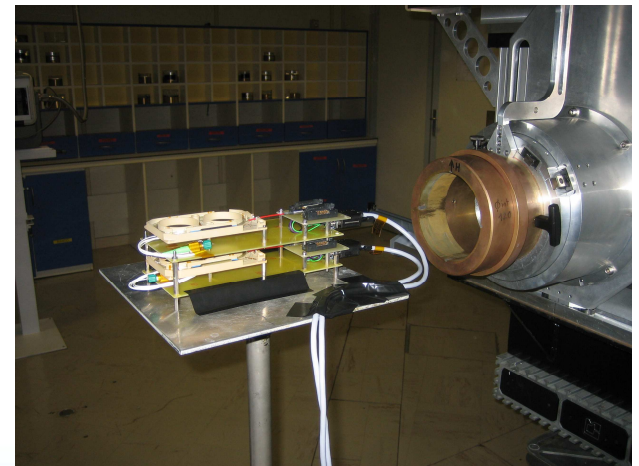
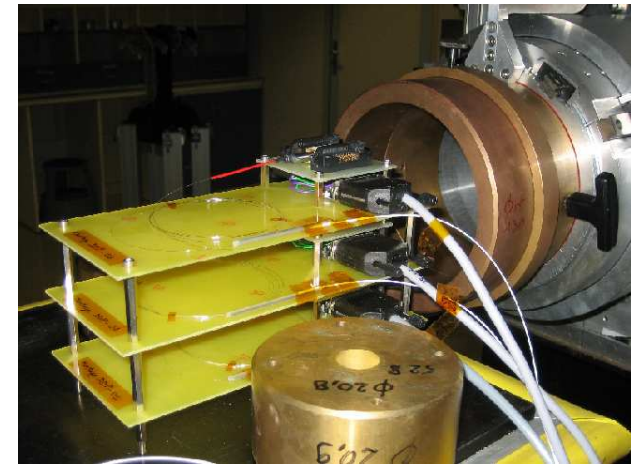
- **Qualification level**

- 2 FOG Sources "ON", 5 FOG Sources "OFF", 100MeV  
Steps :  $3.2e^{10}$  ,  $9,6e^{10}$  &  $1.6e^{11}p/cm^2$*

- **Qualification results**

- FOG Source (included Pump Laser Diode) : nominal working*

- Output Power & Mean Wavelength : a insignificant drift due to the equivalent TID (~4krad)*



# Qualification Results

## Pump Laser Diode : Proton & Gamma irradiation

### ► Total Ionising Dose Qualification

- 3 Pump Laser Diodes

- Qualification level

Parts "ON"

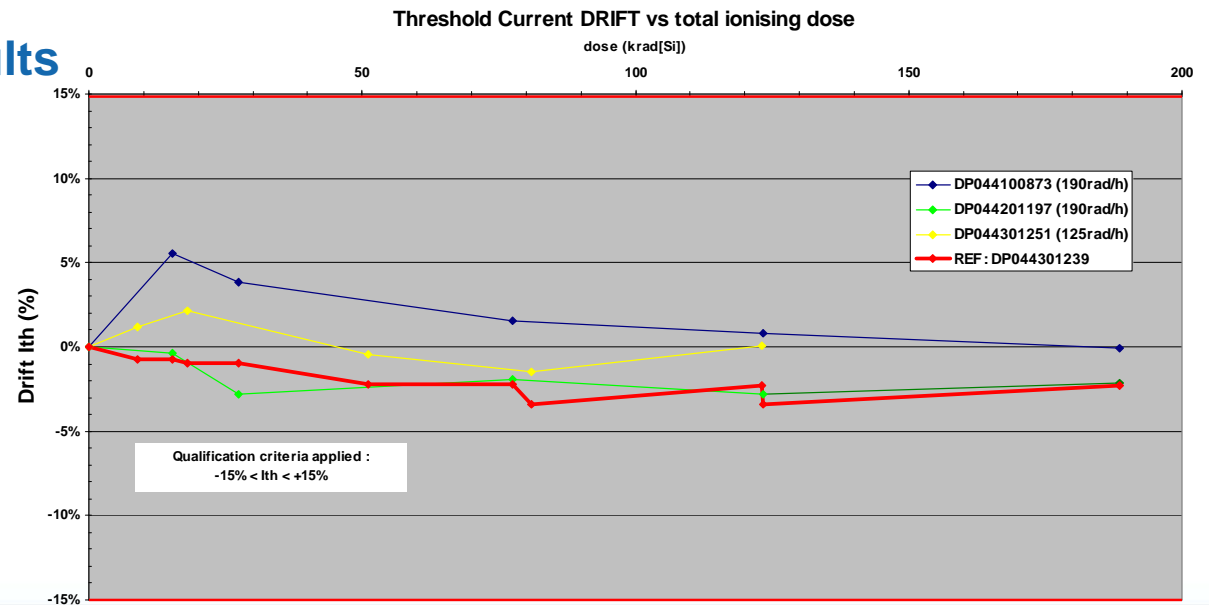
Up to ~190krad[Si], two dose rates : 125rad/h & 190rad/h

5 measurements steps

- Qualification results

$I_{th}$   $I_{nom}$  : nominal value

No drift



# Qualification Results

## FOG Source : Proton & Gamma irradiation

### ► Total Ionising Dose Qualification

- **7 FOG Sources ( ~7 Pump Laser Diodes)**

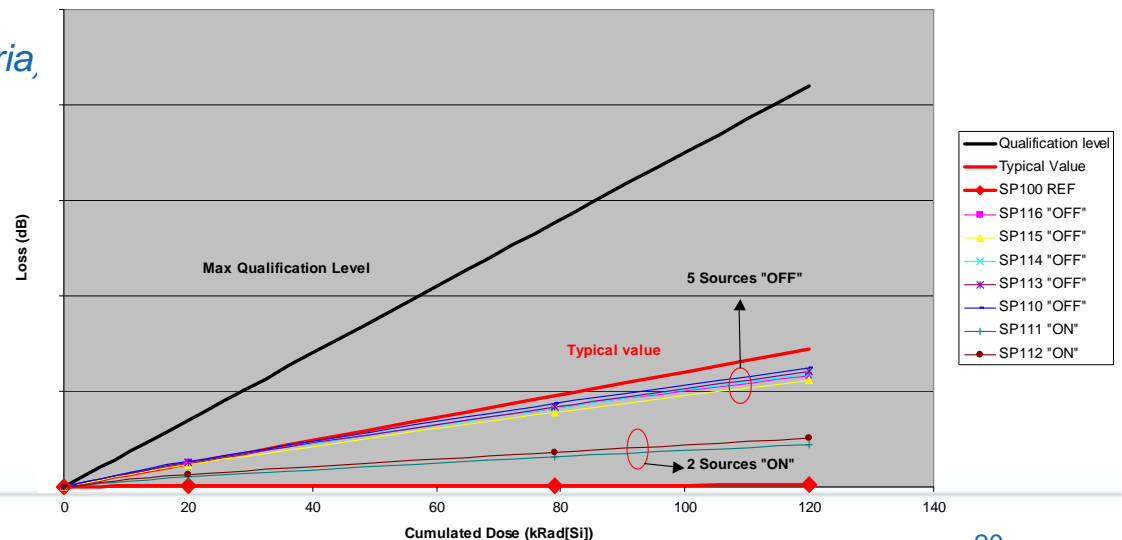
- **Qualification level**

*2 FOG Sources "ON" & 5 FOG Sources "OFF"*  
*TID = 120krad; steps @20, 80 & 120krad*

- **Qualification results**

*Output power drift because of Er fiber*  
*Drift of the mean wavelength*  
*is nominal (< qualification criteria,*

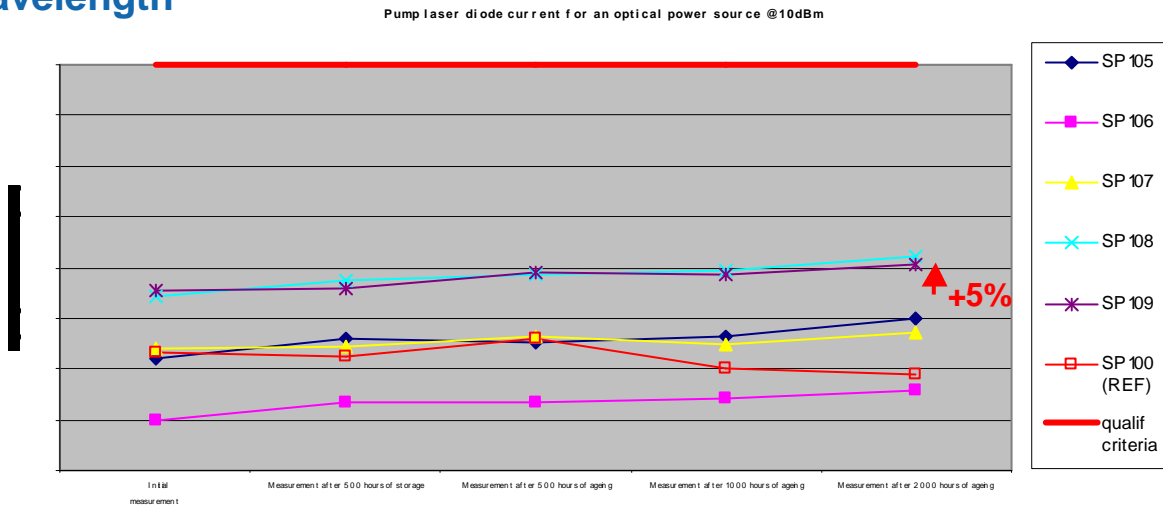
Qualification Results : 7 sources gamma irradiated



# Qualification Results

## FOG Source : Storage & Ageing

- **5 FOG Sources ( ~5 Pump Laser Diodes)**
- **Parameters :**
  - Nominal Optical Output Power ( $P_{nom}$ ) as a function of Pump Laser Diode Current ( $I_{mA}$ )
  - Stability of the Spectrum @  $I_{nominal}$  (<130ppm)
- **Results :**
  - Nominal current : no drift, measurement consistent with the reference
  - No drift of the mean wavelength (<13ppm limit of measurement)



→ No drift indicative of pump laser diode failure

## Qualification Results

# Pump Laser Diode : Thermal Vacuum Life Test

- ▶ **(Temp = 70°C, Pressure <math><10^{-4}</math> atm, up to 3000h, polarized parts)**
  - **The 3 Pump Laser Diodes are plugged, on a socket to be able to supply the diodes**
  - **These sockets are placed on a metallic plate, thermally regulated at 70°C**
  - **The three Pump Laser Diodes are placed into a vacuum chamber**
  - **Each part are pigtailed to permit to realize measurement on the diodes**



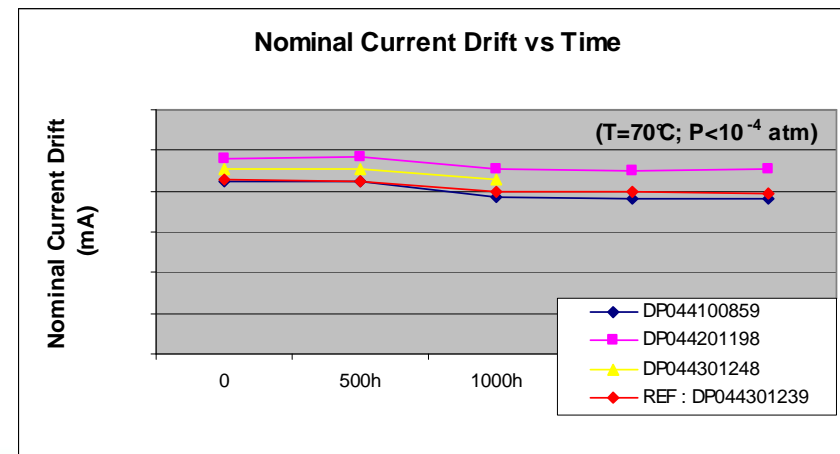
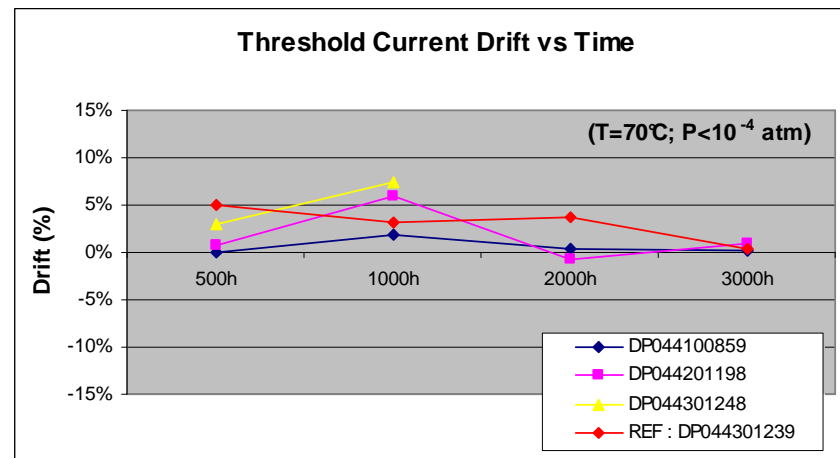
Test performed at CNES premises

## Qualification Results

# Pump Laser Diode : Thermal Vacuum Life Test

### ► Results

- **I<sub>th</sub> : maximum drift of 5%**
  - **Nominal current : no drift, measurement consistent with the reference**
- **No drift indicative of pump laser diode failure**
- **No Package Induced Failure after 3000hours**



# Conclusion

- ▶ **29 pump laser diodes used for the qualification**  
*for 130 parts procured !*
  - **2 parts as reference**
  - **5 parts for Initial DPA**
    - 1 PIND Tested failed
  - **4 parts for Vibration+Shocks+Thermal cycling → OK**
  - **8 parts for Life test**
    - 5 parts : Storage + Dry heat → OK
    - 3 parts : Thermal vacuum → OK
  - **10 parts for Protons + TID → OK**



# Conclusion

- ▶ **The qualification results available to date show that this Pump Laser Diode should be compatible with the space environmental requirements.**

*The final analysis is in progress*

- ▶ **Some final DPA are still in progress.**

- ▶ **In spite of procurement scheme holding account of :**

- **Technology information (iXSea experience, Construction Analysis....)**
- **Planning constraints...**
- **EADS Astrium as Space Qualification Experts**
- **...**

- **A total of ~30% of parts of the strategic procurement are rejected**

→ ~10% in IVE/RX investigations

*Some parts were used for qualification...*

→ ~30% in PIND Test

→ ~7% in upsampling functional tests

# New project and prospects

## ▶ **SWARM** *survey of the geomagnetic field*



- **Magnetometer Helium sensor of the CEA (LETI Grenoble) :**

- Research of opto-electronics and passive optical components for a fibre laser (Parts Justification Documents)
- PMP risk analysis, DCL, DML, DPL , mechanical design...
- PMP activity plan for the Procurement, Qualification & Manufacturing

## ▶ **Others**

- at your disposal ...